Ebert Composites Corporation

New Machine to Create Superior Composite Structures

A composite is made up of two or more materials with their superb properties combined into one high performance product. The typical structure of a composite is a combination of fiber reinforcement and a polymer matrix. Composite products are lighter in weight yet stronger than comparable metal, glass, or wood products. In the late 1990s, however, the quality of some U.S. fiber-reinforced composite products, when compared to metal, lacked strength and were costly to manufacture. Poor performance was due mainly to an inadequate fiber-reinforcement structure and an inefficient manufacturing process.

In March 1998, Ebert Composites Corporation, a small composites manufacturing and research company, turned to the Advanced Technology Program (ATP) and proposed a dramatic improvement in the reinforcement properties of composite products used in place of metal. Ebert envisioned developing an automated, cost-effective machine capable of precisely inserting reinforcing z-axis or vertically (90 degree) oriented fibers into horizontally constructed x-y composite laminate. The end product would be a lightweight, three-dimensional (3-D) composite bar stock that is strong in all three (x, y, and z) directions and could be cut into industrial-use bolts and fasteners. The high-risk challenge for Ebert lay in the fact that existing automated processes did not include 3-D fiber depositing, contributing to composite strength limitations.

With ATP support, Ebert worked from November 1998 to October 2001 to develop an automated 3-D fiber placement machine. While a mid-project market change forced Ebert to adjust their anticipated end-product application, at the conclusion of the project the company had created an innovative machine that produced lightweight, high-performing, sandwich panel structures for transportation and construction applications. Ebert called this new composite material "TRANSONITE."[1] The development of TRANSONITE led to three patents and four trade publication articles. In 2003 Ebert licensed TRANSONITE to Martin Marietta Composites.

In 2005, Ebert and Martin Marietta Composites won industry awards for both the invention and the use of TRANSONITE. As of 2006, Martin Marietta Composites was manufacturing truck trailers and rail cars composed of TRANSONITE. By late 2007, Ebert anticipates that its subsidiary, TRANSONITE Air Cargo Container (TACC) Corporation, will begin to manufacture TRANSONITE air cargo containers. Ebert expects that these lightweight containers will penetrate the aluminum-dominated cargo container market, which will result in significant fuel savings.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * *

Research and data for Status Report 98-01-0097 were collected during June 2006.

Improvements Needed in Quality and Cost

A composite is made up of two or more materials bound together to form a product that offers the superb properties of each separate material. Composites, whether used to replace rubber, glass, metal, plastic, or wood products, have attractive characteristics such as light weight, high strength, and ability to be custom

[1]TRANSONITE is a registered trademark of Ebert Composites Corporation.

designed and fabricated into complex shapes for very specific uses. In the late 1990s, however, some composites had limitations that included weakness under certain amounts of loading. These limitations were traced to inadequacies in the fiber-reinforcement structure (they possessed two-dimensional (2-D) or x-y/cross-directional reinforcements only) and an ineffective manufacturing process. Preformed 2-D woven fabric “sheets” were stacked onto one another, forming plies (layers sewn or fused together) and a single laminate, without three-dimensional (3-D) or z-directional (90-degree angle) fibers or reinforcement. This resulted in delamination or separation of the plies, which weakened the laminate. For many applications, the weaker 2-D composite product is acceptable; however, these 2-D composites are susceptible to significant cracking or delamination and are inadequate for use in construction and transportation. Methods to strengthen fiber-reinforcement properties in the z-direction, including 3-D braiding or weaving of fibers, were slow, costly, and excessively elaborate. Moreover, they could only provide improvement with customized, small-sized laminates less than 1 inch thick and 48 inches wide.

Because of the strength limitations associated with 2-D composites, industry leaders’ perceptions regarding these products were mostly negative throughout the 1990s. Indeed, it was felt that until fiber-reinforced composites had properties similar to steel, composites would continue to be viewed with skepticism by the civil engineering and academic fields. The lack of isotropic properties (that is, equal x, y, and z directional strength) was the most common weakness of composites and was often the focal point of criticism and lack of acceptance from industry and research laboratories. By the late 1990s, however, Ebert Composites Corporation, a small composites manufacturing and research company, was prepared to offer an innovative solution that addressed both composite weakness and costly manufacturing.

Ebert Proposes Dramatic Advancements in Composites

In early 1998, Ebert sought to develop an automated, fiber-placement machine that was capable of depositing z-axis (90-degree vertical angle) glass reinforcement fibers through multiple layers of x-y axis (cross-directional horizontal) fibers using a standard pultrusion manufacturing process. Ebert proposed effective, low-cost, 3-D (x-y-z binding of reinforcement fibers) composite processing that would insert fiber reinforcements in laminate sheets up to 1 inch thick and 48 inches wide.

2-D composites are susceptible to significant cracking or delamination and are inadequate for use in construction and transportation.

The new technology would incorporate the company's sophisticated computer numerical control (CNC) techniques that had the capability to deposit large quantities of glass fiber through multiple layers of composite material. (Ebert had advanced its CNC technology during a 1994 ATP-funded project.) The process was combined with composite pultrusion techniques. Pultrusion is the method of manufacturing cured composites by pulling raw, dry fiberglass material through a resin bath, followed by a heated die. This creates a continuous composite, and is fully automated process. The end result would be the ability to manufacture stronger, low-cost composite bar stock (solid plates) or laminates that could be machined into cost-efficient and effective bolts, fasteners, and washers for U.S. industries.

The technology proposed was innovative and high-risk. In 1998, no technique existed that could rapidly deposit z-axis bundles of reinforcement fibers along the z-axis of a composite laminate by a pultrusion manufacturing process. Because Ebert could not guarantee the successful development of a 3-D fiber-insertion machine, they were unable to obtain private investment funding. Therefore, the nine-employee company turned to ATP for support and a cost-shared project arrangement.

Existing 3-D stitching technology was not effective because the needles severed the glass fibers. A special fiber-placement device, and ultimately an array of such devices, would have to be developed that could precisely deposit a given length of fiber through up to 30 layers of woven reinforcement material. This process would need to be performed while the stack of composite material was moving at production rates as fast as two feet per minute (a manufacturing standard). Additionally, the end product must exceed the quality and performance of existing composites. Ebert won an ATP award and from November 1998 to October 2001, the company worked to develop an automated 3-D fiber-insertion machine, a high-risk undertaking.

Strategy Is Developed to Create New Fiber-Insertion Machine

Ebert identified a number of technical project objectives, including developing new fiber-reinforcement designs. However, if the company was to reach its goal of producing superior composite materials, there were three high-risk objectives it would have to achieve:

- **Development of a single-fiber-insertion device capable of depositing z-directional fibers into a laminate.** Ebert would develop a z-axis, fiber-placement device and method for demonstrating and advancing the concept of depositing fibers perpendicular to a 2-D array of fiber bundles.

- **Development of a multiple-fiber-insertion machine capable of depositing z-directional fibers into a laminate.** With a basic, single-fiber-insertion device developed, a multiple-fiber-insertion prototype, with an appropriate control system, would need to be constructed and integrated into an automatic fabrication machine. Ebert anticipated that the end materials produced by a multiple-fiber-insertion machine would be superior to state-of-the-art composite laminates.
- **Automated production of 3-D composite laminate that exceeded existing laminate strength and size.** With a multiple-fiber-insertion prototype assembled and successfully tested, Ebert would then incorporate this machine into a modified composite pultrusion process. The company sought to produce large bar stock (solid plates) that were lightweight, had strength properties that were nearly equal in all directions, and were capable of replacing many metal products. Producing these sheets in an automated process would significantly lower the cost of manufacturing quality fiber-reinforced composites. However, to achieve these goals, Ebert would need to meet the following specific end-product and processing results:

Product maximum width of processed part	48 inches
Product maximum thickness of processed part	2 inches
Product maximum 3-D insertions per square inch	9 insertions
Product maximum 3-D fiber density	25 percent
Process maximum design line speed	24 inches per minute

Year One: Single, Z-Directional Fiber-Insertion Device Is Created

The first major hurdle in the development of a z-axis, fiber-insertion device was to create a concentric, hollow, or circular tube that could precisely open, close, and cut the glass fibers as the tube entered and then exited the laminate. This probe, a critical part of the insertion device, was expected to properly insert fiber into the composite laminate in a clean and rapid fashion. It was critical that this probe enter, and then exit without causing damage to the x-y fibers already in place in the laminate.

During testing, the innovative prototype successfully inserted more than 2 million fibers into test laminates.

During the first half of year one, Ebert created a prototype device that automatically threaded z-axis glass fibers through x-y axis fibers. Ebert called this new device or tube its “pathway deposition probe” (PDP). While this was an important technical breakthrough, the researchers encountered an unexpected hurdle: during insertion, the PDP caused slightly more than acceptable cracking of the x-y fibers. Ebert researchers soon discovered an extremely unique and proprietary method to accomplish this feat. This discovery led to a patent filing, with additional, innovative machine and processing techniques possibly patentable. By the second half of year one, Ebert had successfully demonstrated that a single probe device could deftly penetrate the 2-D fiber stacks and align and move back through the stack to deposit z-axis fibers. Having proven the one-fiber-bundle and one-PDP concept, Ebert successfully assembled and operated a prototype of its single-fiber-insertion device. Encouraged by test results, Ebert immediately started to design the first-generation, multiple-insertion x-y-z composite structure prototype. This design would be seven side-by-side deposition mechanisms operating over an area six inches wide.

Year Two: First-Generation 3-D Multiple-Fiber-Insertion Machine Is Built

During the first months of year two of the ATP-funded project, Ebert began assembling the seven-probe-array prototype. One of the major problems Ebert needed to address was motion control of this new assembly. The company found that using new hydraulics on an advanced CNC stepper-hydraulic cylinder and servo control (mechanized motion control) of the side-to-side motion; they could achieve excellent fiber-insertion control. In fact, using CNC-type motion control instead of a pneumatic operation allowed Ebert to achieve greater density of z-fibers, resulting in added strength. This technique would also allow the possibility of manufacturing large composite sheets. Midway through year two, in fact, after several modifications were made to the prototype to enhance reliability and speed, the synchronous pultrusion of a 1-inch-thick laminate was made with 16 fiber bundles per square inch. The development of laminate sheets beyond existing sizes (48 inches) was becoming a real possibility. During the fourth quarter of year two, Ebert successfully built and tested its seven-probe, six-inch-wide prototype. During testing, the innovative prototype successfully inserted more than 2 million fibers into test laminates. At the end of year two, Ebert was ready to build a full-scale, automated, 3-D fiber-insertion machine.

However, despite technical breakthroughs, midway through year two Ebert had learned that Taiwanese companies had begun producing low-cost stainless steel fasteners and had proceeded to flood the U.S. market. The company's original plans to produce low-cost bar stock (solid plates) for industry, which would have competed with the costly stainless steel, now seemed pointless. However, their technical successes and the possibility of effectively manufacturing large-size (panel) laminates were leading to other possible applications. Based on the strong probability of producing a viable product with multiple applications, the project continued.

Year Three: Automated Production of New 3-D Composite Laminate

Following additional modifications to the fiber-insertion device and control systems, Ebert was ready to begin production of the next generation of fiber-reinforced composite laminates. Manufacturing would occur on a composite production machine that featured the new z-directional PDP, enhanced CNC motion control, and modified pultrusion process. Figure 1 depicts Ebert's new machine performing this process.

Figure 1. Ebert's new pultrusion process to manufacture 3-D fiber-reinforced composites.

During the second quarter of year three, Ebert successfully pultruded a composite sandwich panel, which was composed of multiple layers of composite of varying thicknesses. These panels had six layers of x-y glass fibers on both the top and bottom, with a foam core in the middle. The successful deposition of 16 z-directional fiber bundles per square inch resulted in a new 3-D sandwich with dramatically improved strength. While an existing composite sandwich structure with no 3-D fibers tested to a compression strength of approximately 30 pounds per square inch (psi), the new sandwich with the 3-D fibers did not fail until it reached more than 2,500 psi, an exceptional improvement in strength.

In addition to dramatic improvements in composite strength, Ebert also met or exceeded all of its project objectives for width, length, fiber density, and manufacturing line speed. The company exceeded expectations in the area of fiber insertions per square inch of laminate, achieving 16 instead of 9. The end result was a stronger, lighter material composite sandwich panel produced at a reduced cost. Ebert called this panel “TRANSONITE” (depicted in Figure 2). TRANSONITE is a lightweight, high-strength, highly durable composite sandwich panel consisting of a fiber-reinforced polymer laminate as skin layers and a foam core. The top and bottom face sheets are supported by and tied together with through-thickness z-directional fibers, giving TRANSONITE its unique structure. The new composites can also be manufactured as bar stock (solid plates) for cutting, as well as manufactured for a specific application such as truck or container wall panels. TRANSONITE can be produced in sizes that range from one-half to 4 inches thick and up to 102 inches wide.

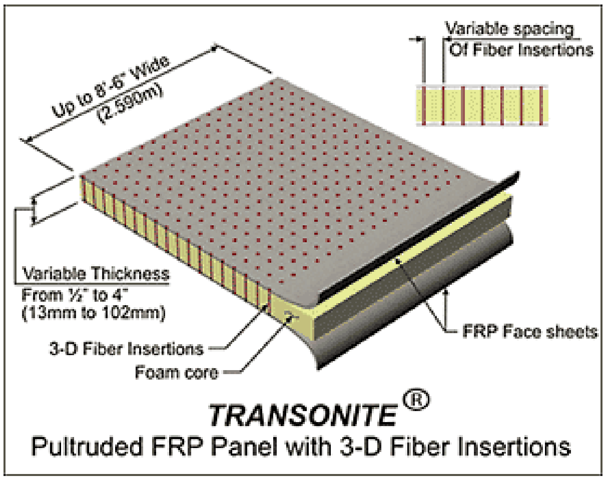

Figure 2. Schematic view of a finished TRANSONITE sandwich panel. TRANSONITE features variable fiber placement, allowing for the manufacturing of laminate sheets of different sizes that are equal in strength. The width of TRANSONITE can be up to eight feet, six inches, and the thickness, supported by z-axis fibers, can range from one-half to four inches. The result is a fiberglass reinforced plastic (FRP) panel with intertwined fibers oriented in three directions.

The new TRANSONITE sandwich panels proved so effective that even before the ATP-supported project had ended in October 2001, Ebert received two contracts from U.S. military agencies to supply the 3-D fiber sandwich structure. Three weeks after Ebert announced the benefits of TRANSONITE, the U.S. Air Force (through the Navy Surface Warfare Center) awarded the company a contract to replace existing aluminum matting with TRANSONITE in temporary airfields and runways. Under this agreement, TRANSONITE panels were first used at Tyndal AFB, Panama City, Florida. The second contract was to fabricate TRANSONITE trailer panels for the United States Navy.

TRANSONITE Enters the Open Market and Wins Acclaim

In 2002, Ebert started to market its new product. As a small, privately held corporation, however, they lacked the resources to make the new technology readily available to American industry. Based on suggestions from ATP, the company determined that licensing would provide the broadest and most immediate economic impact to the U.S. economy. Ebert identified and contacted 20 potential manufacturers in 2002. For potential licensees and manufacturers, the worldwide market for lightweight, composite sandwich structures was estimated at $10 billion. In 2003, Martin Marietta Composites signed as a licensee of TRANSONITE. Impressed by the product’s uses and strength, Martin Marietta Composites and Ebert broadened the licensing agreement to increase the number of product applications. For example, because of TRANSONITE’s strength properties, it could also be used in the construction and transportation sectors. In an amendment to the original license with Ebert, Martin Marietta Composites agreed to commit 12 million square feet to manufacturing capacity.

In addition to dramatic improvements in composite strength, Ebert also met or exceeded all of its project objectives for width, length, fiber density, and manufacturing line speed.

In 2005, Ebert and Martin Marietta Composites won awards from the American Composites Manufacturers Association for TRANSONITE’s unique construction and multiple applications. TRANSONITE won the “Infinite Possibility” award, which is given to the product that “demonstrates the potential to significantly increase the use of composites in existing or developing markets, or generate the biggest impact to open markets.” TRANSONITE also won the "Technical Innovation for Corrosion Application" award, which is presented to the product that “best incorporates corrosion-resistant features in the final product.” Building on its successes and expected future uses for TRANSONITE, Ebert continued to develop the product.

The fiber-insertion machine reached its fifth generation of development in 2006. Among the advancements was the capability to insert 32 fiber bundles per square inch, a twofold increase in fiber density since the conclusion of the project in 2001. As of 2006, Martin Marietta Composites was using TRANSONITE technology in a number of applications, including truck trailer and rail car panels. Ebert has manufactured, certified, and shipped three 102-inch-wide pultrusion machines equipped with TRANSONITE technology to Martin Marietta's manufacturing facility. In addition to current applications, TRANSONITE is designed and available for other uses such as bar stock (solid plates), air cargo containers, lumber replacement, recreational equipment, ballistic panels, marine construction, bridge decks, and industrial mats.

In 2006, Ebert Composites was in the process of obtaining private investments to fund TRANSONITE Air Cargo Container (TACC) Corporation, a subsidiary that will build air cargo containers using the lightweight but strong composite panels. As TACC garners financial backing, Ebert also expects to obtain Federal Aviation Administration approval to use TRANSONITE for the containers. By late 2007, Ebert expects TACC to begin commercial operations.

These new TRANSONITE containers will be 25 to 30 percent lighter than the lightest existing aluminum air cargo containers. Because TRANSONITE containers are lighter than conventional containers, their use will result in significant customer savings in reduced fuel expenditures. Additionally, using less fuel will lead to diminished carbon dioxide emissions and, consequently, less greenhouse gas in the atmosphere. The exclusive use of TRANSONITE composite containers throughout the worldwide air cargo industry would result in environmental and economic benefits.

Conclusion

In November 1998, Ebert Composites Corporation began a three-year ATP-funded project to develop a cost-efficient, three-dimensional (3-D) fiber-reinforced composite material that could compete with heavier, more costly materials such as steel and aluminum. Initially, they wanted to make bar stock (solid plates) that could be machined into strong but less expensive composite bolts and fasteners. During 1999, Ebert achieved technical success in developing a machine that could more effectively insert fibers into composite materials, which would significantly increase the structural integrity and strength of that composite product. When Taiwanese companies flooded the U.S. market with low-cost stainless steel fasteners, a product that would compete directly with Ebert's proposed composite materials, the company turned to producing large-size (panel) composite laminates that would have many uses. Ebert discovered that the devices and processes that could make near-isotropic (nearly equal in strength in all directions) bar stock (solid plates) could produce 3-D fiber-reinforced "sandwich" panels.

By the conclusion of the project in October 2001, Ebert had achieved technical, manufacturing, and application successes. The company had created an innovative, 3-D multiple-fiber-placement machine and had incorporated the new fiber insertion method into a modified composite pultrusion or manufacturing system. The new multiple-insertion process produced composite sandwich panels with a thickness that was from one-half to 4 inches and a width of up to 102 inches. Ebert's new composite product, TRANSONITE, is a lightweight, high-strength, highly durable composite sandwich panel consisting of fiber-reinforced polymer laminates and a foam core. Ebert's successes led to three patents and four articles in trade publications. In 2003, Martin Marietta Composites signed as a licensee of TRANSONITE. In 2005, Ebert and Martin Marietta Composites won industry awards for the unique construction and multiple applications of TRANSONITE. Ebert has continued to enhance the ATP-supported technology, developing the fifth-generation fiber-insertion machine in 2006. In the same year, Martin Marietta Composites was using TRANSONITE technology in a number of applications, including truck trailer and rail car panels. Also in 2006, Ebert created the TRANSONITE Air Cargo Container (TACC) Corporation, a subsidiary formed to build air transportation cargo containers. Ebert anticipates that TACC will begin commercial operations by late 2007.

PROJECT HIGHLIGHTS
Ebert Composites Corporation

Project Title: New Machine to Create Superior Composite Structures (3-D Fiber Deposition Processing: The Development of Near-Isotropic Composite Bar Stock)

Project: To design, build, and demonstrate a prototype machine that precisely and rapidly places reinforcing glass fibers through layers of composite material, enabling the low-cost manufacturing of composite parts that are uniformly strong in three dimensions.

Duration: 11/1/1998 - 10/31/2001
ATP Number: 98-01-0097

Funding (in thousands):

ATP Final Cost	$1,941	73.6%
Participant Final Cost	698	26.4%
Total	$2,639	

Accomplishments: With ATP funding, Ebert Composites Corporation accomplished the following:

- Created an automated, multiple-fiber-insertion machine for the production of large-sized (48 inches wide by 4 inches thick), fiber-reinforced composite sandwich panels.
- Developed lightweight, high-strength composite sandwich panels with exceptionally strong and stable 3-D reinforcement fibers. Ebert called these new fiber-reinforced composite panels "TRANSONITE."

In 2005, Ebert and Martin Marietta Composites (Ebert's licensee of TRANSONITE) won awards from the American Composites Manufacturers Association for TRANSONITE's unique construction and multiple applications. TRANSONITE won the "Infinite Possibility" award, which is given to the product that "demonstrates the potential to significantly increase the use of composites in existing or developing markets, or generate the biggest impact to open markets." TRANSONITE also won the "Technical Innovation for Corrosion Application" award, which is presented to the product that "best incorporates corrosion-resistant features in the final product."

Ebert Composites received the following three patents:

- "Method of inserting z-axis reinforcing fibers into a composite laminate"
(No. 6,645,333: filed August 2, 2001, granted November 11, 2003)
- "Method of clinching the top and bottom ends of z-axis fibers Into the respective top and bottom surfaces of a composite laminate"
(No. 6,676,785: filed November 19, 2001, granted January 13, 2004)
- "3D fiber elements with high moment of inertia characteristics in composite sandwich laminates"
(No. 7,056,576: filed June 8, 2004, granted June 6, 2006)

Commercialization Status: In 2003, Ebert Composites issued a license to Martin Marietta Composites for the manufacturing and sale of TRANSONITE composite panels. From 2003 to 2006, TRANSONITE composite panels were sold for use in rail car and trailer truck walls and panels. TRANSONITE is also designed and available for other uses such as bar stock (solid plates), air cargo containers, lumber replacement, recreational equipment, ballistic panels, marine construction, bridge decks, and industrial mats.

Outlook: The outlook for Ebert's TRANSONITE product is strong. By late 2007, Ebert Composites expects to begin manufacturing air cargo containers from TRANSONITE. This manufacturing will be done by its subsidiary, TRANSONITE Air Cargo Containers (TACC) Corporation.

Composite Performance Score: * * *

Number of Employees: 9 at project start, 11 as of June 2006

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PROJECT HIGHLIGHTS
Ebert Composites Corporation

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- James Hook
  Alpine, CA

- Dr. Vistasp M. Karbhari
  University of California at San Diego
  San Diego, CA

Publications:

- Berg, Tom. “All-Composite Live-Floor Trailer, Hands-on Trucking.” *Reed Business Information*, June 1, 2001.

- “New Trailers Debut at Mid-America.” *PRIMEDIA Business Magazine*, May 1, 2005.

- Salgado, Brian. “Keeping the Deck Stacked: Martin Marietta Composites Markets Its Fiber-Reinforced Polymer Products to Bridge Engineers as an Alternative to Concrete and Steel Grating in Specialized Markets where Weight is a Critical Consideration.” *Schofield Media Group*, September 1, 2005.

- “Fiber-Reinforced Trailer Wins ACE Award.” *PRIMEDIA Business Magazine*, January 1, 2006.